

## **Gravity-Dependent Combustion and Fluids Research - From Drop Towers to Aircraft to the ISS**

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Driven by the need for knowledge related to the low-gravity environment behavior of fluids in liquid fuels management, thermal control systems and fire safety for spacecraft, NASA embarked on a decades long research program to understand, accommodate and utilize the relevant phenomena. Beginning in the 1950s, and continuing through to today, drop towers and aircraft were used to conduct an ever broadening and increasingly sophisticated suite of experiments designed to elucidate the underlying gravity-dependent physics that drive these processes. But the drop towers and aircraft afford only short time periods of continuous low gravity. Some of the earliest rocket test flights and manned space missions hosted longer duration experiments. The relatively longer duration low-g times available on the space shuttle during the 1980s and 1990s enabled many specialized experiments that provided unique data for a wide range of science and engineering disciplines. Indeed, a number of STS-based Spacelab missions were dedicated solely to basic and applied microgravity research in the biological, life and physical sciences. Between 1980 and 2000, NASA implemented a vigorous Microgravity Science Program wherein combustion science and fluid physics were major components. The current era of space stations from the MIR to the International Space Station have opened up a broad range of opportunities and facilities that are now available to support both applied research for technologies that will help to enable the future exploration missions and for a continuation of the non-exploration basic research that began over fifty years ago. The ISS-based facilities of particular value to the fluid physics and combustion/fire safety communities are the Fluids and Combustion Facility Combustion Integrated Rack and the Fluids Integrated Rack.



# ***Gravity-Dependent Combustion and Fluids Research***

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***From Drop-Towers, Aircraft, and Rockets to the STS and the ISS***

David L. Urban, Bhim S. Singh and Fred J. Kohl

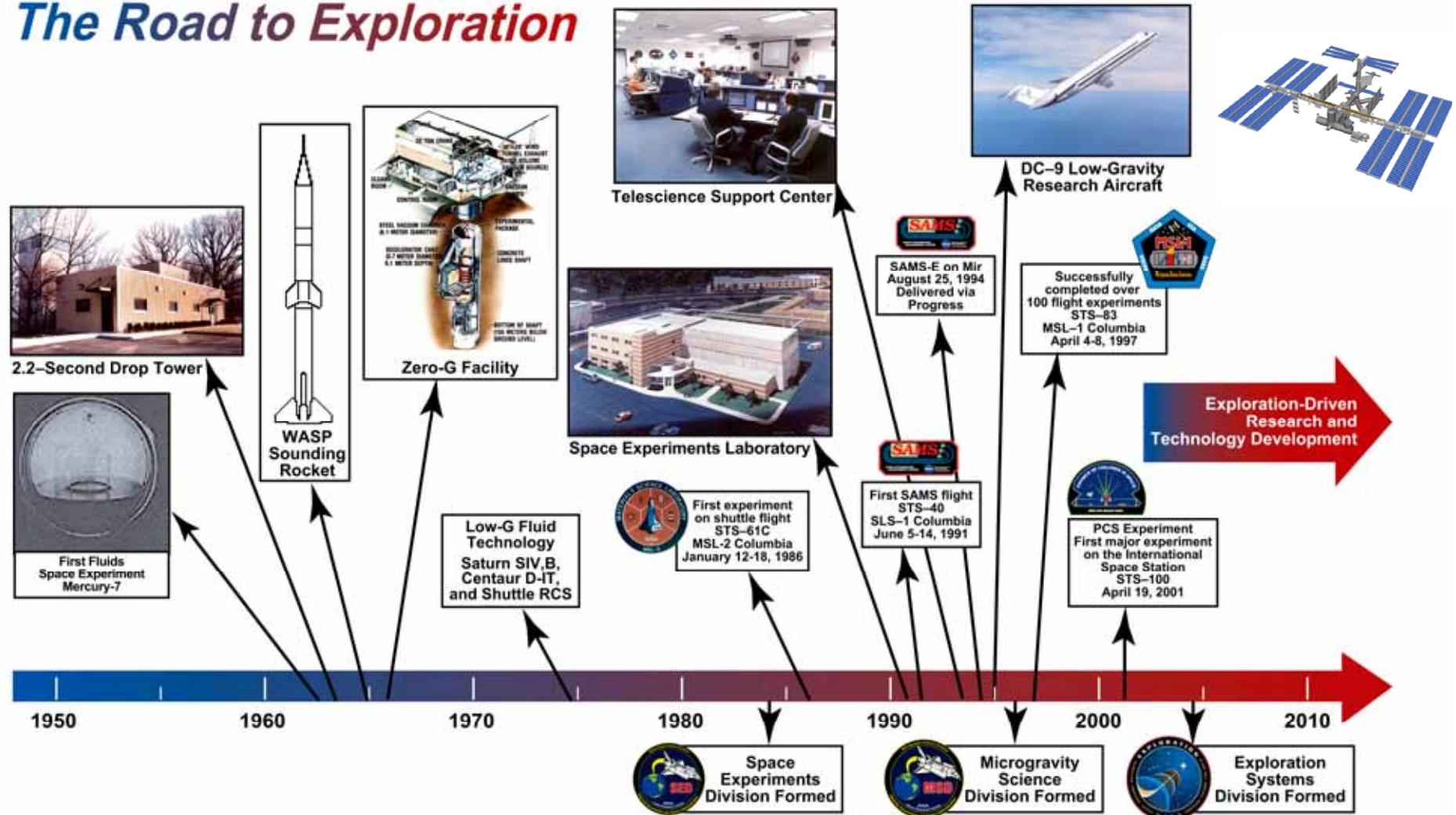
May 25, 2007

**International Space Development Conference 2007**  
Dallas, TX



# Historical Trend in Low-Gravity Research

## *The Road to Exploration*





# Early Low-Gravity Research

Drop-towers used to produce lead shot circa 1780

Earliest Drop-Tower Combustion Research

Droplets: Kumagi (Japan) ~ 0.5 second Mid 50's

Earliest Spacecraft (manned) experiment: Propellant Management in low-Gravity (Mercury)

The Skylab space station (mid 70's) supported a significant microgravity research program much of it devoted to human health with a smaller physical science program supporting experiments in:

Fire Safety

Fluids and Materials Processing, Crystallization



# **NASA Microgravity Physical Sciences Research Program History (Highly Simplified)**

- 1960's** Drop-towers constructed, research largely in-house
- 1970's** PACE (Physics and Chemistry Experiments) and MPS (Materials Processing in Space) programs brought in outside investigators
- Early 1980's** Microgravity Program formed
- Late 1980's** First large NRA's --10's of investigations selected per discipline:
  - Fluids, Combustion, Materials, Fundamental Physics, Biotechnology
- 1990's** Extensive use of the Shuttle (middeck, SpaceLab and USMP)
- Late 1990's** First Exploration research topics funded (FPDS, ISRU, ELS etc)
- 2004** VSE announced
- 2006** End of large scale Fundamental Research program
  - Transition to Exploration Program with 15% Non-Exploration Research still funded

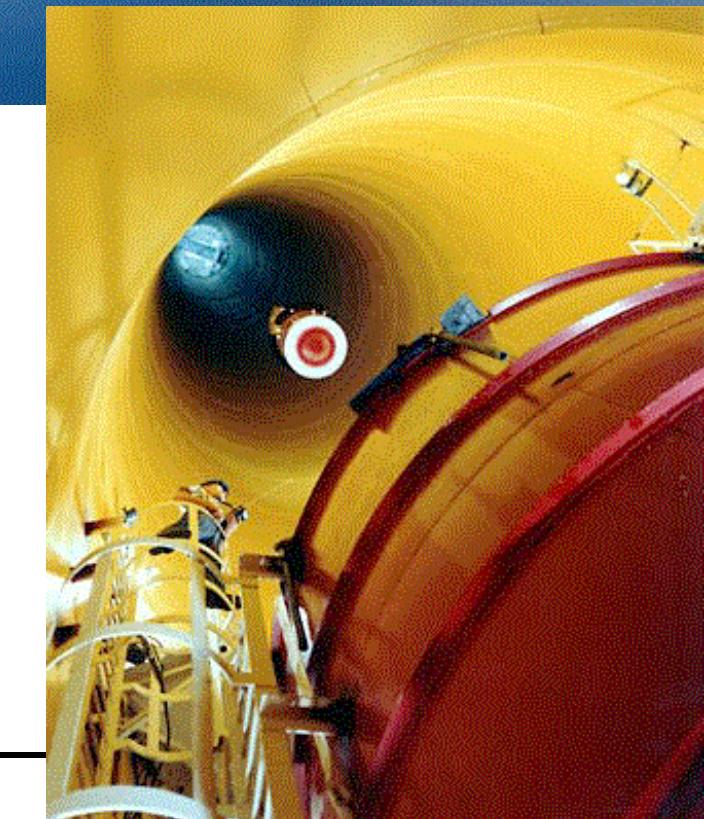
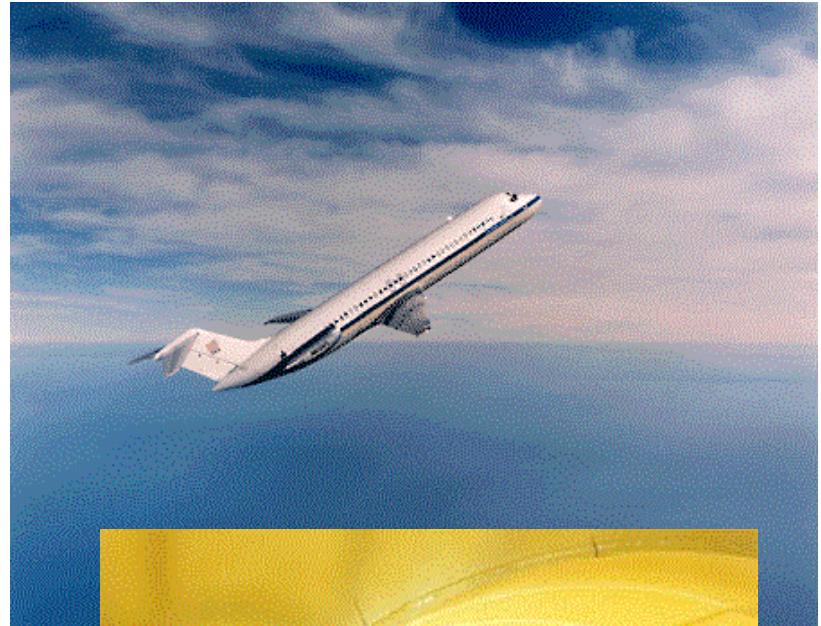
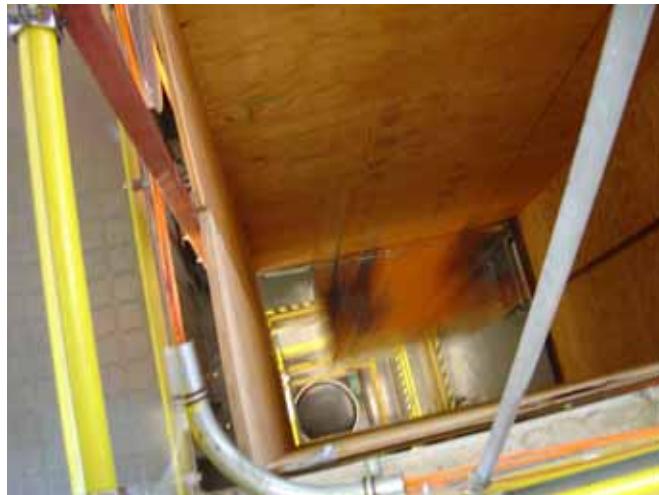
## US Ground Based Low-Gravity Facilities

Low-g aircraft

Drop-Towers

2.2 Second

5.2 Second



# Combustion Science Research Transformation



## Combustion Science and Chemically Reacting Systems



## Human Support Systems Exploration Research

### Combustion Science and Chemically Reacting Systems-Based

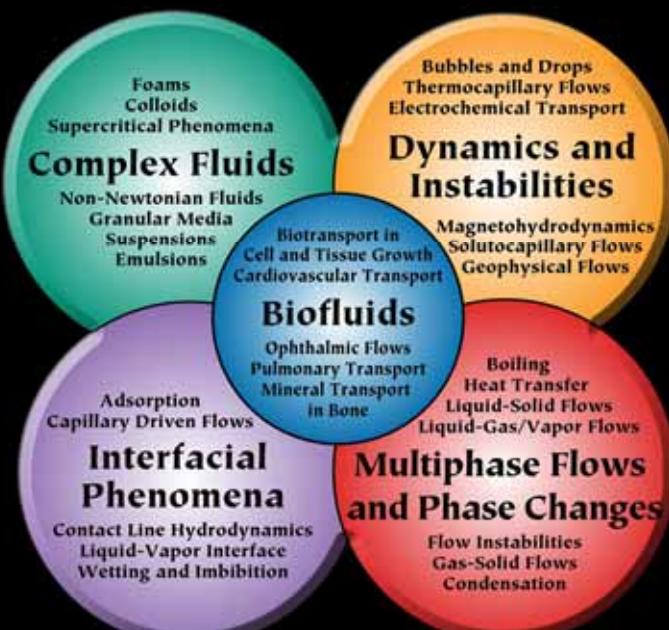
- Fire prevention, detection, and suppression systems
- Extravehicular activity technologies
- In-situ resource utilization
- In-situ fabrication and repair
- Environmental monitoring and control systems





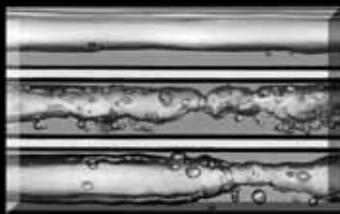
# Fluid Physics Research Transformation

## Microgravity Fluid Physics



## Fluid Physics-Based Exploration Research

- Advanced life support
  - Air revitalization systems
  - Water recovery system
  - Solid waste management system
  - Thermal systems
  - Advanced food technology
- Advanced extravehicular activity technologies
- Power generation and propulsion systems
- Environmental monitoring and control
- Multiphase flow technologies





# **ISS Research Project**

**Exploration:** To utilize the ISS as a test bed for technology development, demonstration, and problem resolution in the areas of life support, fire safety, power, propulsion, thermal management, etc.

- Facilities: Combustion Integrated Rack (CIR), Fluids Integrated Rack (FIR), Multi-User Droplet Combustion Apparatus (MDCA), Light Microscopy Module (LMM).
- Experiments related to Fire Safety: Fire Prevention, Detection, and Suppression.
- Experiments related to heat transfer, boiling and thermal management.
- Experiments related to fluids management for propulsion and life support systems.

➤ **Goals:** To provide ground-based and space flight hardware that will advance Explorations capabilities and support the generation of research data for science and technology experiments.

➤ **Heritage:**

- Office of Biological and Physical Research Program
- Microgravity Research Program
- Advanced Life Support/ Life Support and Habitation Program
- Life Science Program

**Non-Exploration:** To support ground-based, free-flyer, and ISS life and microgravity science research that is not directly related to supporting the human exploration program.

- Instruments: Acceleration Environment Characterization
- Combustion Science Experiments
- Colloids and Liquid Crystals
- Material Science and Fluids Physics Experiments
- Fluid Flow and Heat Transfer

# ISS Research Project - Current Content



**Exploration:** To utilize the ISS as a test bed for technology development, demonstration, and problem resolution in the areas of life support, fire safety, power, propulsion, thermal management, etc.



Program Management



Fluids and Combustion Facility (FCF)

*FHA: 5/07, 95% complete*



Multi-User Droplet Combustion Apparatus (MDCA)/FLame Extinguishment eXperiment (FLEX)

*FHA: 5/07, 100% complete*



Light Microscopy Module (LMM)/Constrained Vapor Bubble experiment (CVB)

*FHA: 11/07, 85% complete*



Smoke Aerosol Measurement Experiment (SAME)

*Shipped, 100% complete*



Dust and Aerosol measurement Feasibility Test (DAFT)

*On-Orbit, operations*



Boiling eXperiment Facility (BXF)

*FHA: 10/07, 70% complete*



Capillary Flow Experiment (CFE)

*On-Orbit, operations*



Gaseous Combustion (CIR/MDCA Follow-on P/L)

*FHA: 01/10, 0% complete*

**Non-Exploration:** To support ground-based, free-flyer, and ISS life and microgravity science research that is not directly related to supporting the human exploration program.



Space Acceleration Measurement System (SAMS)

*On-Orbit, operations*



Microgravity Acceleration Measurement System (MAMS)

*On-Orbit, operations*



Coarsening in Solid-Liquid Mixtures-2 (CSLM-2)

*FHA: 4/08, 90% complete*



Shear History Extensional Rheology Experiment (SHERE)

*FHA: 4/07, 95% complete*



Smoke Point in Coflow Experiment (SPICE)

*FHA: 5/08, 40% complete*



Binodal Colloidal Alloy Test (BCAT-4)

*FHA: 9/07, 75% complete*



Investigating the Structures of Paramagnetic Aggregates from Colloidal Emulsions-2 (InSPACE-2)

*FHA: 5/07, 90% complete*



FLame Extinguishment eXperiment-2 (FLEX-2)

*FHA: 10/08, 5% complete*



Zero Boil-Off Tank Experiment (ZBOT)

*FHA: 01/10, 5% complete*



Capillary Channel Flow (CCF)

*FHA: 01/08, 40% complete*



PI Support, Grants

*FOAM, OASIS, GRADFLEX*



Colloids (FIR/LMM Follow-on P/L)

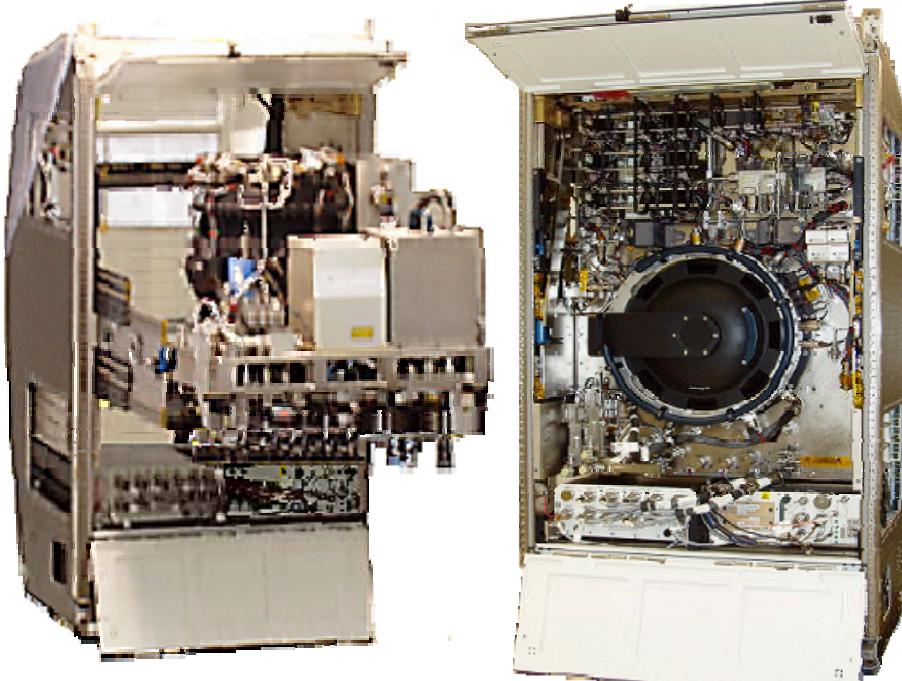
*FHA: 6/10, 5% complete*



# ISS Fluids and Combustion Facility (FCF)

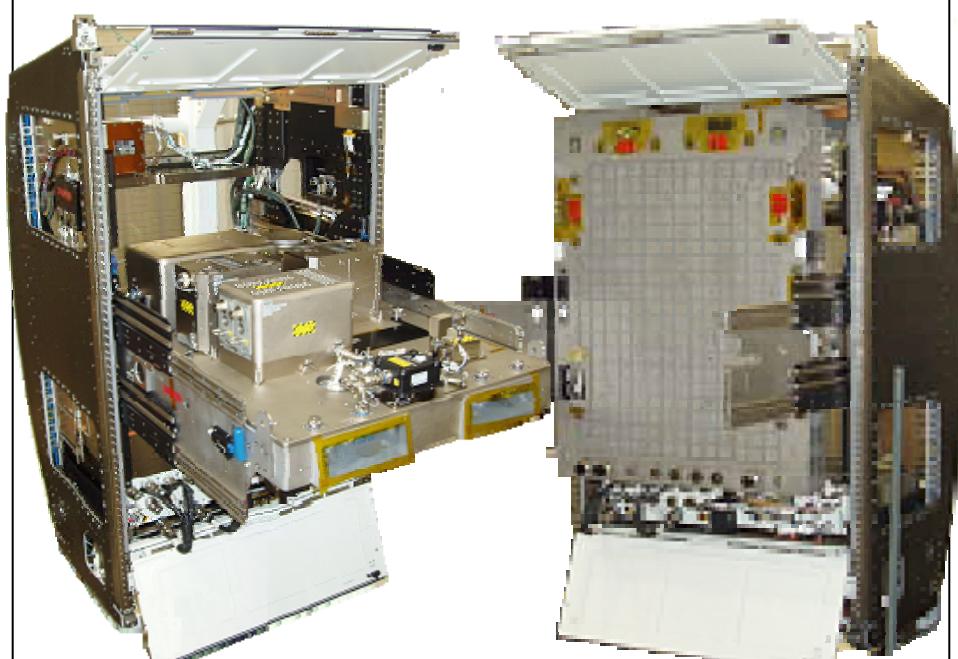
## ***Combustion Integrated Rack (CIR)***

CIR provides the only large environmental chamber (100 liters) on ISS in which the space environment or Lunar, Mars or planetary surface environments can be simulated (i.e., pressure, temperature, gaseous atmospheres, particulates, etc.) for long duration, on-orbit investigations and technology validations.



## ***Fluids Integrated Rack (FIR)***

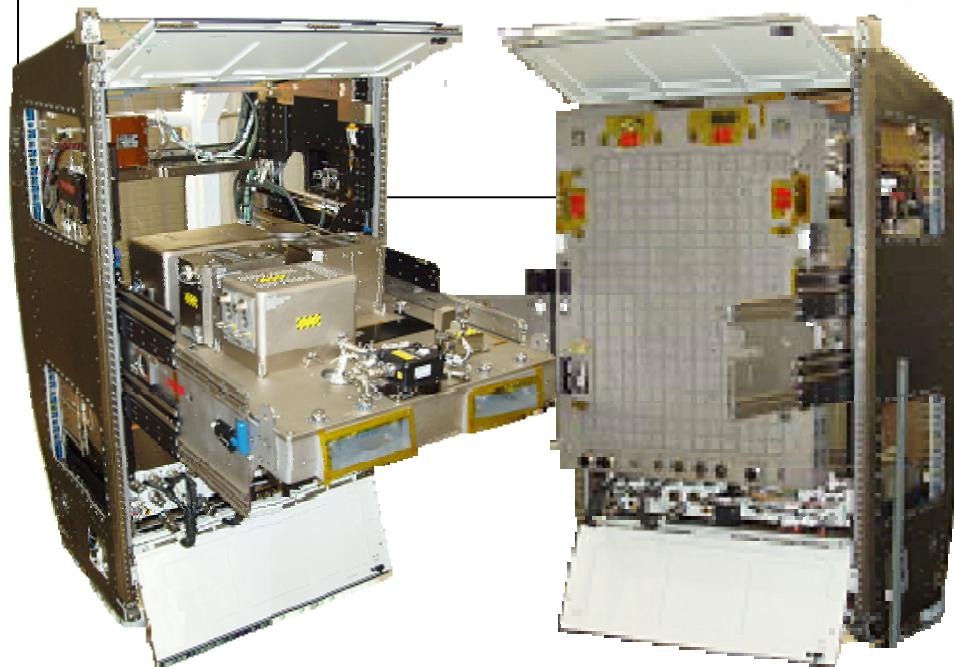
FIR provides the largest, contiguous volume for experimental hardware of any ISS facility, easily reconfigurable diagnostics, customizable software, active rack-level vibration isolation, and other subsystems that are required to support a wide range of Exploration Systems Investigations





## ***FCF Fluids Integrated Rack (FIR)***

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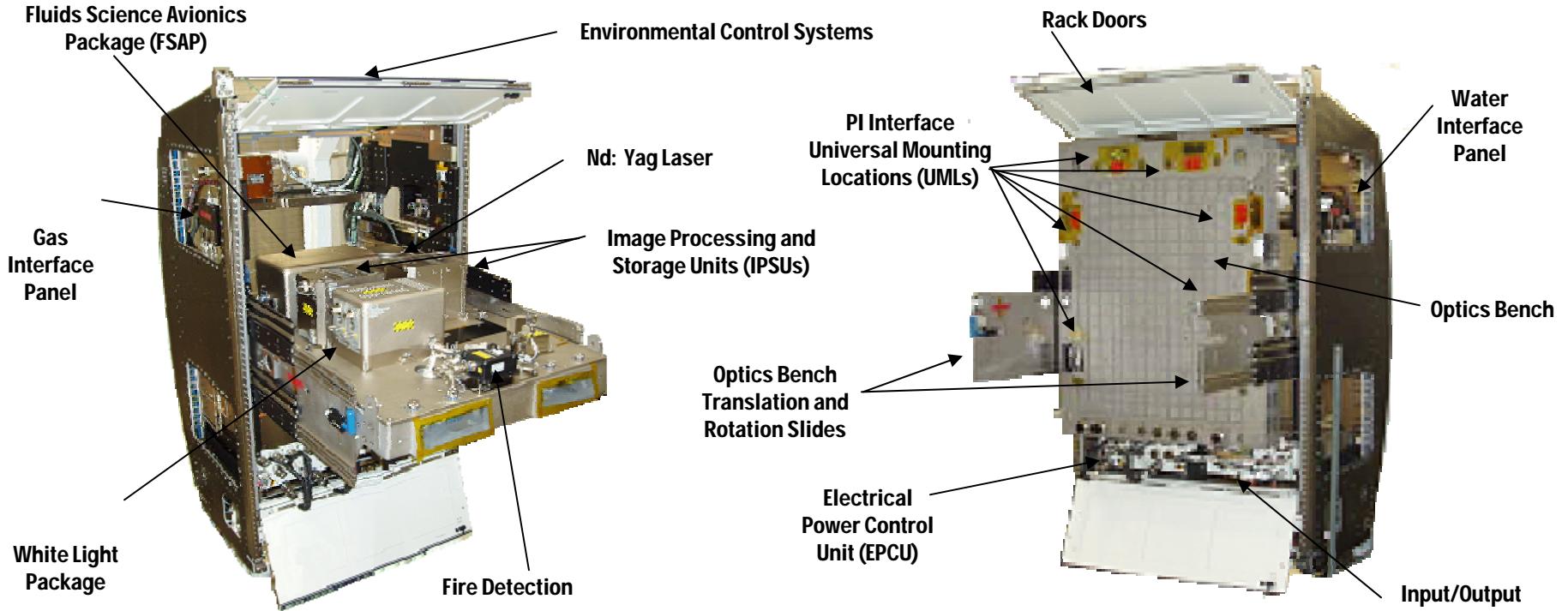


### **FIR Capabilities**

- FIR's large configurable volume, 0.49m<sup>3</sup>, provides a flexible platform required for Fluids Physics Based Exploration Investigations.
- FIR's optics bench allows for precise alignment of coupled (optical, mechanical) hardware.
- FIR's efficient power system can provide sufficient power required by Fluids Physics Base Exploration Investigations (nominally provides over 2.1 kW of power up to 3 kW max).
- FIR provides a thermally controlled environment via 3kW of water cooling and 1.3 kW of air cooling.
- FIR provides experiments with an advanced state-of-the-art data acquisition and control system (analog & digital I/O's, motion control, RS-422, Ethernet, Analog video, IEEE 1394 FireWire, 860 GB of data storage)
- FIR provides diagnostics required by Fluids Physics Based Exploration Investigations (cameras & light sources)



## Fluids Integrate Rack (FIR) PI Resources/Capabilities



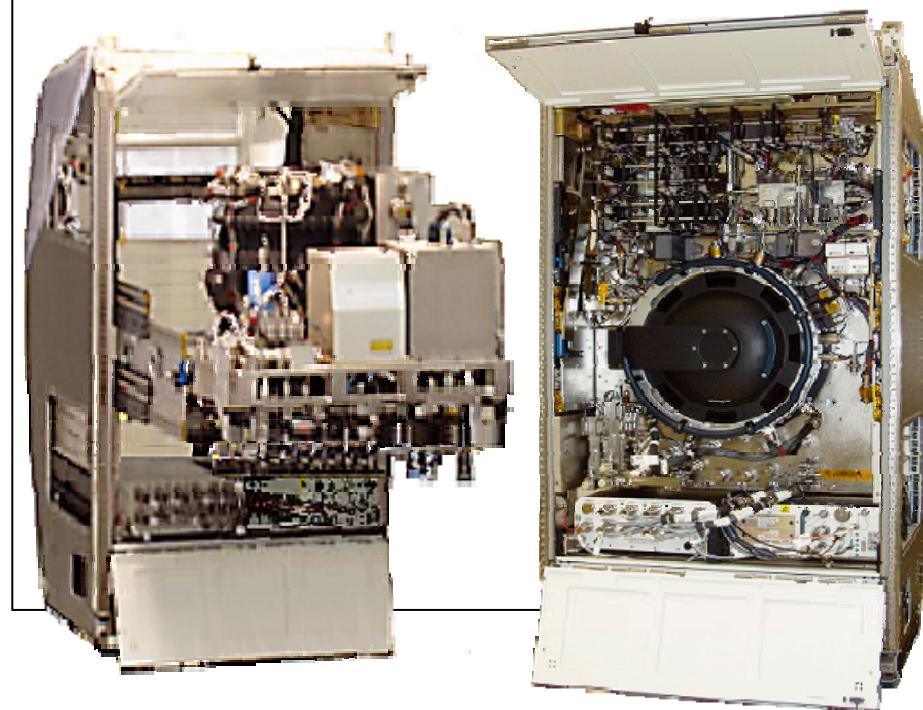
- Volume ~ 0.49 m<sup>3</sup> (1100mm x 895mm x 495mm)
- Mass ~ 250 to 300kg depending on FIR be utilized
- Power
  - 672 W/1600W max at 28Vdc
  - 1450 W at 120Vdc
- Thermal Cooling
  - 3 kW water (MTL)
  - 1300 W air (provided at 20°C to 30°C)

- Video
  - Analog Color Camera
  - C-IPSU - IEEE 1394 FireWire & Analog Frame Grabber Interfaces for PI provided cameras
  - C-IPSU - Image processing & storage units for real time and post processing of image data
  - Illumination – White Light & 150mW & 532nm Nd:YAG LASER
- Control & Data Acquisition
  - FSAP - Standard control and data acquisition interfaces (e.g. analog & digital I/O's, motion control, RS-422)
  - MDSU & IOP - 860 GB of Data Storage



# FCF Combustion Integrated Rack (CIR)

CIR provides the only large environmental chamber (100 liters) on ISS in which the space environment or Lunar, Mars or planetary surface environments can be simulated (i.e., pressure, temperature, gaseous atmospheres, particulates, etc.) for long duration, on-orbit investigations and technology validations.

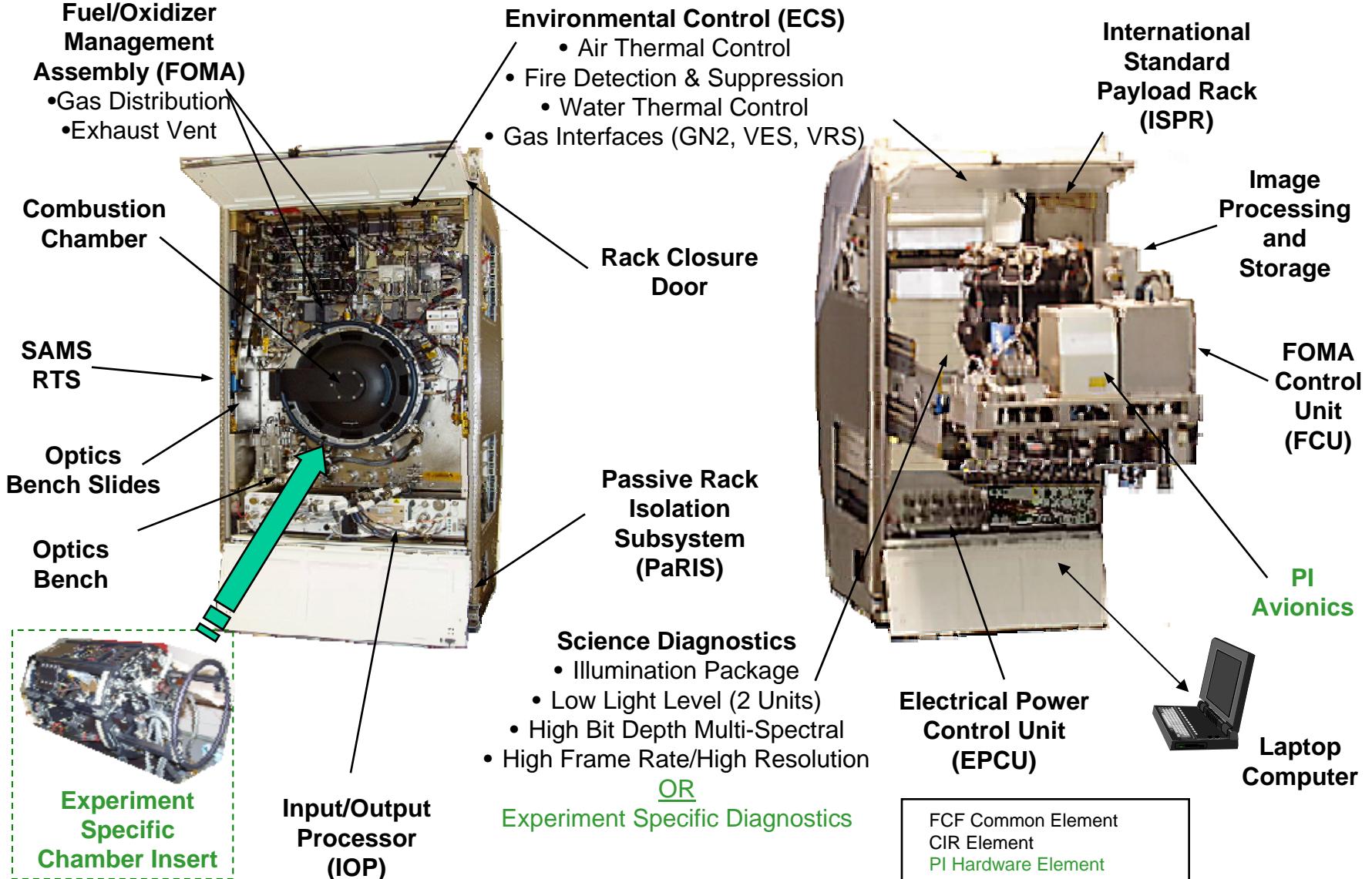


## Combustion Capabilities

- Combustion chamber with a free volume of 100 Liters, dual seal chamber door and 8 windows.
- Gas supply system with three gas manifolds that supply up to 30 standard liters per minute (90 slpm total) with one manifold supplying up to 85% O<sub>2</sub>.
- Gaseous fuel supply system which provides gaseous fuel at up to 2 standard liters per minute.
- High resolution digital (1000 X1000 pixels) camera capable of 100 frames per second at 8 bits
- A high bit depth digital (1000 X1000 pixels) camera capable of 15 frames per second at 12 bits.
- A Low Light Level- Infrared camera with a spectral range of 400-900 nanometers.
- A Low Light Level- Ultraviolet camera with a spectral range of 250-700 nanometers.
- A Gas Chromatograph capable of measuring the as constituents in a range from .1 to 98% with a precision of +/- 2% of reading.
- Image Processing and Storage units with 72 GB of storage each.



## Combustion Integrated Rack (CIR) PI Resources/Capabilities





# Microgravity Science Glovebox (MSG)

WBS: 825080.05.06.01



PM: Linda B. Jeter

Engineering Teams: SDOS, Sverdrup, COLSA, HEI

## ♦ Objective:

- ♦ To provide a facility onboard the ISS to conduct research/technology demonstrations by:
  - Providing an enclosed isolated working volume with distributed resources for the implementation and observation of Investigations
  - Providing for facility integration and support of selected experiments
  - Successfully supporting the operation of research investigations/technology demonstrations through their assigned mission segments

## ♦ Relevance/Impact:

- ♦ The MSG can be utilized for multi-Program tasks
- ♦ MSG Team provides over a decade of experience with glovebox and experiment design, build, integration and operation

## ♦ Development Approach:

- ♦ The Microgravity Science Glovebox (MSG) is a double rack facility designed for research investigation handling aboard the International Space Station (ISS). The MSG consists of the Core Facility (CF) and the International Standard Payload Rack (ISPR) with its Standard Payload Outfitting Equipment (SPOE).
- ♦ The MSG facility provides an enclosed working area for investigation manipulation and observation in the ISS. This working area can serve as an isolated environment with a constantly circulating environment that is maintained at a pressure below ambient. This is accomplished by a design that includes multiple air circulation modes, multiple purpose filters and numerous resource accommodations for investigation interface.
- ♦ The MSG Facility was selected for installation and early operation on the ISS. The European Space Agency (ESA) developed the MSG facility in accordance with the Memorandum of Understanding (MOU) between the National Aeronautics and Space Administration (NASA) and ESA.



Marshall Space Flight Center



MSG has been performing research on ISS since 2002

## Experiment Accommodations

Work Volume (0.255m <sup>3</sup> )	906mm wide x 637 mm high 500mm deep (at floor), 385mm deep (at top)
Experiment Size	Max 406mm diameter (insertion through side port)
Power To Experiments (1000 watts total)	7 amps @ 28volts, 8 amps @ 5 volts 2 amps @ +12volts, 2 amps @ -12volts 8.3 amps @ 120 volts
Heat Dissipation	800 watts from cold plate; 200 watts from air flow
Video	4 video cameras, 4 recorders
Data Handling	Two S422, One MIL-BUS-1553B, Two Ethernet

Revision Date: 05/22/06

## Project Life Cycle Schedule

Milestones	MOU	PDR	CDR	JIP	Eng Unit Del	MSFC CoFR	Flight Unit Del	Launch	Transfer of Ownership	Ops	Return
Actual Dates	3/18/97	3/27/97	10/16/97	10/20/99	7/16/01	3/8/03	10/23/01	6/5/02	8/14/03	Ongoing	TBD



# Materials Science Research Rack (MSRR)



PM: Rodney B. Key

Engineering Teams: MSFC, SDOS, Sverdrup, COLSA, HEI

Marshall Space Flight Center

## Objective:

- ♦ To provide a facility onboard the ISS to conduct materials science research/technology experiments by:
  - Providing a modular facility to accommodate up to two Experiment Modules (EM)
  - Providing for the facility integration of the ESA MSL EM
  - Successfully supporting the planned investigations through the mission
  - Providing resources for experiment modules: power, data, vacuum (resource and exhaust), cooling, microgravity isolation, video.

## Experiment Accommodations

Experiment Volume (Alpha side) (7.3 ft <sup>3</sup> )	31.75" length x 15.7" depth x 25.37" width
Launch Mass Available (Alpha side)	Max – 107 kg (cg constraints must be analyzed)
Power Available To Experiments (1000 watts total)	5 kW maximum based on two payload operations 2 - 10 amp @ 120 Vdc 8 – 10 amp @ 28 Vdc
Cooling Available	MTL Coolant available Maximum pressure drop = 5.5 psi
Video	NTSC signal per EIA/TIA RS-250-C
Vacuum	VES and VRS access
Data Handling	MRDL Ethernet link to LAN-2 MIL-STD-1553B Remote Terminal interface to Master Controller (Bus Controller)

Revision Date: 07/24/06

## Project Life Cycle Schedule

Milestones	LOA	IPL PDR	IPL CDR	JIP	Eng Unit Del	MSFC CoFR	Flight Unit Del	Launch	Transfer of Ownership	Ops	Return
Actual Dates	09/1999	02/2000	04/2002	07/2003	04/2006	TBD	05/2007	TBD	N/A	TBD	TBD

## Relevance/Impact:

- ♦ The MSRR can be utilized for multi-Program tasks
- ♦ The MSRR will accommodate the operation of the European Space Agency Materials Science Laboratory (MSL)

## Development Approach:

- ♦ The MSRR-1 Experiment Carrier (EC) consists of the Rack Support Subsystems (RSS), an Active Rack Isolation System (ARIS) and the International Standard Payload Rack (ISPR) with its Standard Payload Outfitting Equipment (SPOE).
- ♦ The MSRR-1 is a multi-purpose International Space Station (ISS) facility capable of accommodating a wide variety of research experiments to conduct material science and technology investigations in micro-gravity
- ♦ The MSRR-1 Facility is being designed and developed by the Marshall Space Flight Center, this effort is managed out of the Science and Mission Systems Office (VP)





# Space Acceleration Measurement System (SAMS) ISS On-Orbit Operations



PT: ISS Research Project  
PI: N/A  
PM: Robert Hawersaat, GRC  
PS: N/A

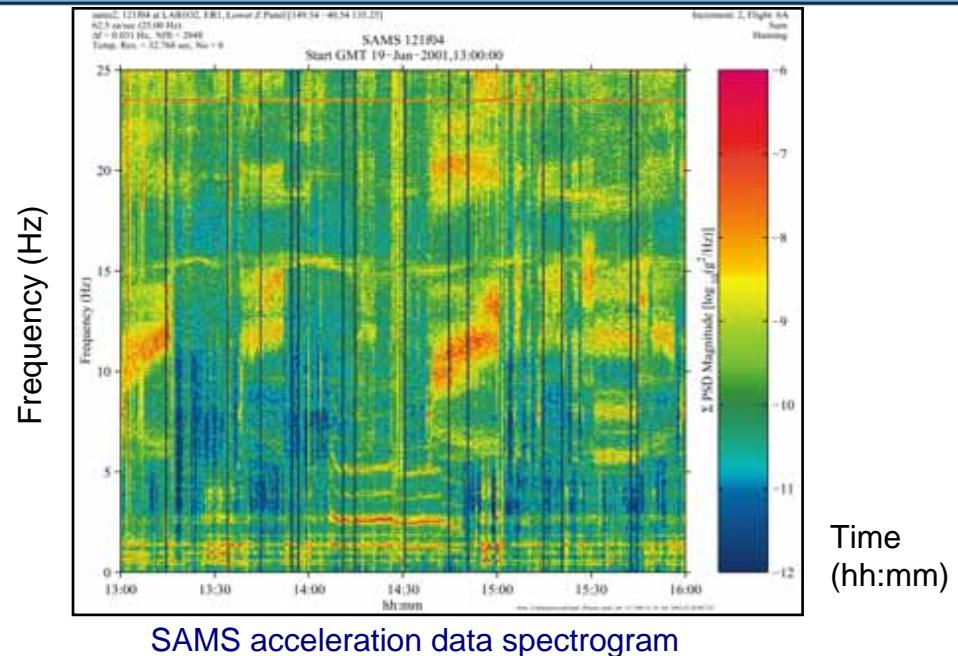
**Objective:** The objective of SAMS is to provide an acceleration measurement system that meets the requirements of the researchers on board the International Space Station. SAMS measures the acceleration environment in the 0.01 to 400 Hz frequency range for payloads.

**Significance:** The SAMS acceleration data provides measurement of the microgravity influence on a payload during science operations.

**Approach:** SAMS was developed using a dedicated function approach using an Interim Control Unit and SAMS laptop for command and control and a Remote Triaxial Sensor to measure the vibratory environment. SAMS sensors are located in the US Lab and one is in the Microgravity Science Glovebox (MSG) facility.



SAMS Interim Control Unit , and ICU with SAMS laptop



SAMS acceleration data spectrogram

## Statistics on SAMS Operations

- SAMS has been operated on ISS starting in Increment 1 (April 2001)
- SAMS sensors have supported payload operations during Increment 1 though 12.
- SAMS was re-activated in March 2007 to support ISS Research payload operations.
- The FCF experiments within the CIR and FIR facilities along with BXF will be supported by SAMS scheduled for flight ULF2.

## Significant Findings

- SAMS provided acceleration data that supported the recent data from CFE Vane Gap-2 indicate a new approach in tank design may be possible. SAMS sensor locations and acceleration data plots are available at the Principal Investigator Microgravity Services (PIMS) website: <http://pims.grc.nasa.gov>



# Microgravity Acceleration Measurement System (MAMS) ISS On-Orbit Operations



PT: ISS Research Project  
PI: N/A  
PM: Robert Hawersaat, GRC  
PS: N/A

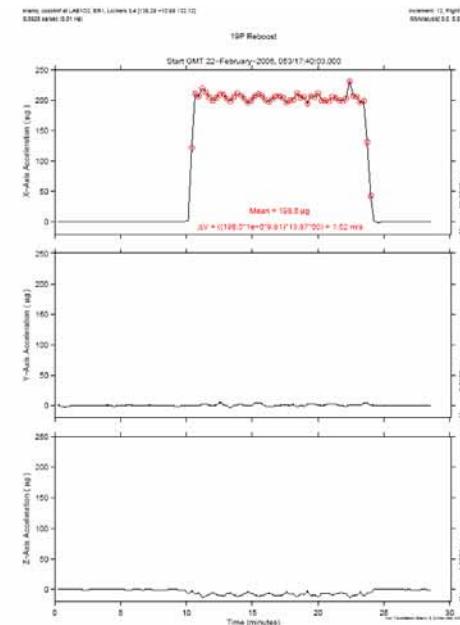
**Objective:** The objective of MAMS is to provide an acceleration measurement system that measures the Quasi-steady and vibratory acceleration data in 0.00001 to 100 Hz frequency range for the ISS vehicle.

**Significance:** MAMS measures the acceleration environment for ISS structure and provides the data to the vehicle dynamics group for analysis.

**Approach:** MAMS was developed to operate with minimum crew interaction, and can be commanded with ground commands. MAMS supports the ISS reboosts, dockings and undockings between Shuttles, Progress, and Soyuz and the ISS. MAMS has also provided data to the ISS vehicle dynamics team in support of crew exercise.



MAMS Front Panel



X-axis

Y-axis

Z-axis

MAMS data for 19 Progress reboost of ISS

## Statistics on MAMS Operations

- MAMS has been operated on ISS starting in Increment 1 (April 2001)
- MAMS sensors have supported reboost operations during Increment 15.
- MAMS can be activated as back up to SAMS if the frequency range for the payload or event is within the MAMS range.
- During the Increment 14 (Oct 2006 to April 2007) MAMS supported 2 Control Moment Gyro # 3 tests, 3 reboosts, 1 test of the Solar Array Wing (P6/4B), and Solar Array Rotary Joint test, and a ISS Thruster Test.

## Significant Findings

- MAMS supported the recent CMG # 3 test, providing valuable data to the vehicle dynamics group for troubleshooting of the control moment gyro isolation to the gyro. Additional information on sensor locations and acceleration data for ISS is available at the Principal Investigator Microgravity Services (PIMS) website: <http://pims.grc.nasa.gov>



# Binary Colloidal Alloy Test (BCAT)-3

## ISS On-Orbit Operations

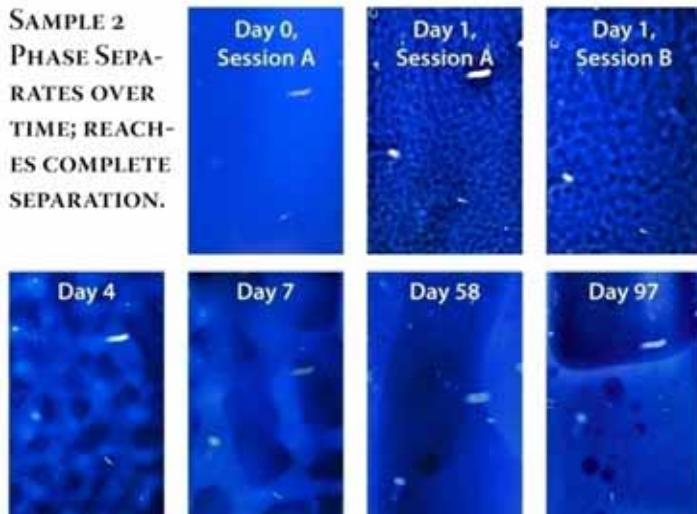


PT: ISS Research Project  
PIs: Prof. David Weitz and Peter Lu, Harvard; Prof. Arjun Yodh, U. Penn  
PM: Ronald Sicker, GRC  
PS: Dr. William Meyer, NCSER

**Objective:** The objective of BCAT-3 is to study the dynamics of phase separation when the masking effects of gravity are removed. BCAT-3 uses model critical fluids, made from mixtures of polymers and colloids; they are prepared over a range of concentrations. The BCAT-3 critical fluid samples either remain homogeneous indefinitely, or like salad dressing, separate into two phases.

**Significance:** The BCAT-3 data points collected in microgravity have extended the observable range for phase separation. One impact: a billion dollar fabric softener business in the US is following this work because they use vesicles (which behave like colloids) and polymer, in solution, to increase viscosity and improve product performance.

**Approach:** BCAT-3 uses EarthKAM, which is set up and optimized by astronauts, to photograph the time evolution of the critical fluid samples contained in a book-sized sample module on the ISS Maintenance Work Area (MWA).



BCAT-3 Sample Module set up on the MWA in the International Space Station. Astronauts Michael Foale (above), Michael Fincke, Leroy Chiao, William McArthur, Jeffrey Williams, and soon Sunita Williams will have performed BCAT-3 operations on the ISS.

### Statistics on BCAT-3 Operations

- BCAT-3 has been operated on ISS starting in Increment 8 (March 2004) through Increment 15 (June 2007) and beyond.
- The samples in the BCAT-3 Slow Growth Sample Module have been homogenized and photographed by crew about 30 times.
- BCAT-3 has had the benefit of significant hands-on astronaut crew involvement (above and beyond what we requested, e.g., Saturday Science).
- 6+ hours of video data were downlinked and recorded on tape.
- 2,213 individual photographic images were downlinked and recorded.

### Significant Findings To Date

- Unprecedented observation of full phase separation, including both spinodal and binodal decomposition. Microgravity is essential to uncover the full range of this fundamental aspect of nature. (Weitz)



# Capillary Flow Experiments (CFE) ISS On-Orbit Operations



PT: ISS Research Project  
PI: Prof. Mark Weislogel, PSU  
PM: Donna Bohman, GRC  
PS: Robert Green, GRC

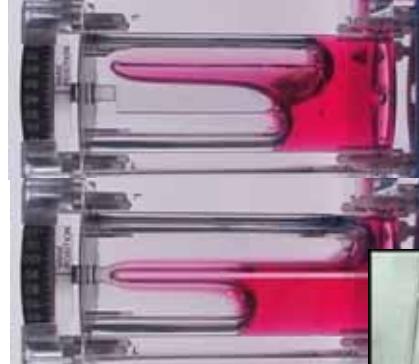
**Objective:** The objective of CFE is to investigate the role of capillary forces in the transport and storage of fluid systems in space. Capillary forces can be exploited to control fluid orientation to enable predictable performance for large mission critical systems involving fluids.

**Significance:** The CFE results will provide an improved understanding of static and dynamic phenomena of the fluid/vapor interface for fluids management aboard spacecraft (fuel/cryo tanks, water processing, etc.) The data provide key boundary condition information for the design of specific systems that can passively exploit container geometry to manage liquid inventories.

**Approach:** CFE consists of six handheld units with different geometries, test fluids, and wetting properties (two each of Contact Line, Vane Gap, and Interior Corner Flow). Units are tested/operated on the ISS Maintenance Work Area (MWA).



Astronauts Michael Fincke, William McArthur, Jeffrey Williams, Michael Lopez-Alegria (not shown) and Sunita Williams have performed CFE operations on ISS.



Vane Gap –1 at 45° and 90° critical vane angle test points.



Contact Line –2  
Slosh disturbance test



Interior Corner  
Flow –2 at equilibrium  
point.

## Statistics on CFE Operations

- CFE has been operated on ISS starting in Increment 12 (8/20/2004) thru Increment 15 (5/12/2007).
- All six CFE modules have been operated at least once. CL-2 has seen the most operational runs (four).
- CFE has operated a total of 15 times and has accumulated a total of 45 astronaut crew hours.
- 30+ hours of video data have been recorded on tape and down-linked. 650+ individual test data points have been recorded.

## Significant Findings to Date

- Recent data from Vane Gap-1 indicate a new approach in tank design may be possible, i. e., exploiting slight asymmetries in the geometry to passively manage large fluid volumes.



# Coarsening in Solid-Liquid Mixtures-2 (CSLM-2) ISS On-Orbit Operations

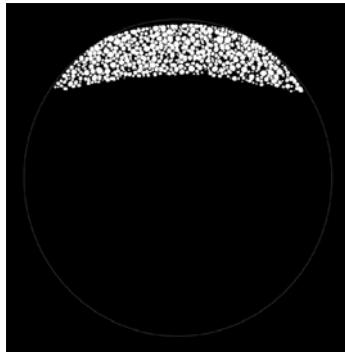


PT: ISS Research Project  
PI: Dr. Peter Voorhees, NWU  
PM: Robert Hawersaat, GRC  
PS: Dr. Walter Duval, GRC

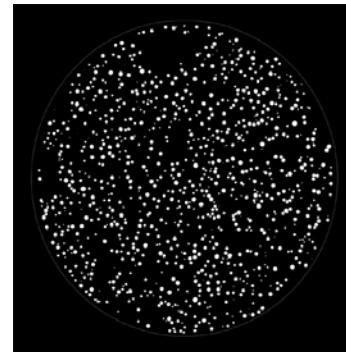
**Objective:** The objective of CSLM-2 is to support the development and accuracy of theoretical models of the Ostwald Ripening (coarsening) process in metallic alloys. CSLM-2 will determine the factors controlling the morphology of solid-liquid mixtures for a two-phase eutectic mixture, determine the steady state dependence of the rate constant, particle size distribution, and particle spatial distribution on the volume fraction of the coarsening phase.

**Significance:** The CSLM-2 experiment will aid in materials selection for high temperature materials, such as nuclear propulsion and waste heat coolant tubes. The CSLM-2 results will improve design codes that are based on incomplete models and databases.

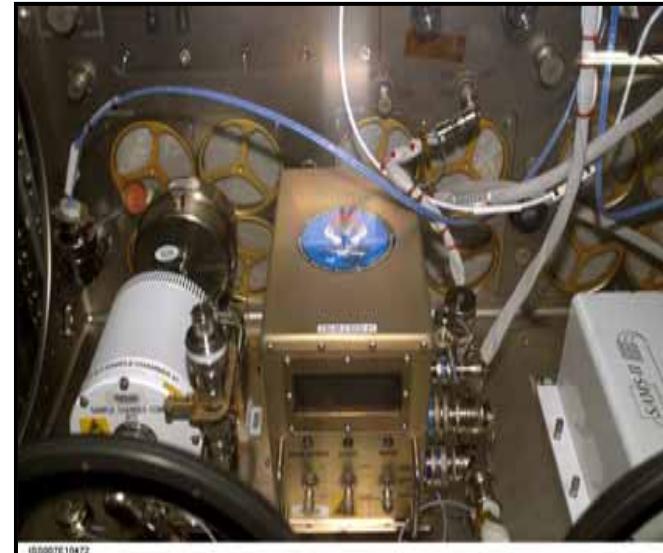
**Approach:** CSLM-2 hardware consists of an Electronic Control Unit (ECU) and five Sample Processing Units (SPU).



Ground-Based Sample



CSLM-1 Sample from MSL-1



Flight SPU # 1 and Flight ECU # 1 installed in the MSG on board ISS.

## Statistics on CSLM-2 Operations

- CSLM-1 was operated during Shuttle mission MSL-1 in July 1997.
- CSLM-2 was operated on ISS during Increment 7 in August 2003 with 2 SPU engineering units.
- One CSLM-2 ECU operates with one SPU, each SPU contains 4 samples with a specific volume fraction of tin-rich particles in a lead-tin alloy.

## Significant Findings

- The interface between the Sn-rich particles and the Sn-Pb eutectic are easily identifiable. The PI obtained an accurate measurement of the average particle size in this solid-liquid mixture with data that can be used to analyze the coarsening process.



# Dust and Aerosol measurement Feasibility Test (DAFT) ISS On-Orbit Operations



PT: ISS Research Project  
 PI: David Urban, GRC  
 PM: William Sheredy, GRC  
 PS: Gary Ruff, GRC

**Objective:** The objective of DAFT was to evaluate the performance of the TSI P-Trak, a commercially available condensation nuclei counter in a microgravity environment. The P-Trak will be used as a key diagnostic for the Smoke Aerosol Measurement Experiment (SAME), which is manifested for delivery to the ISS on the 13A.1 mission.

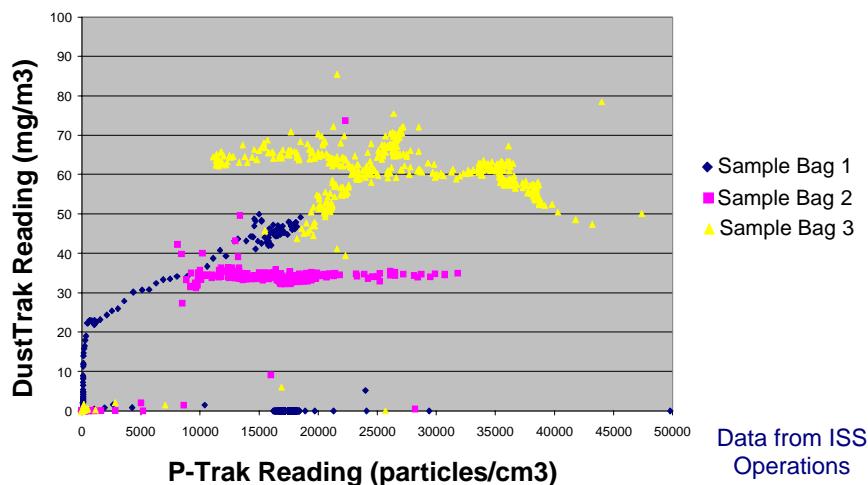
**Significance:** Demonstration of the P-Trak's performance in a long-duration microgravity environment has mitigated a significant technical risk to the success of SAME. The results from SAME will lead to the rational development of advanced fire particulate detectors for exploration vehicles and habitats.

**Approach:** Operate the P-Trak while sampling a known aerosol, Arizona Road Dust (ARD), from a custom particle delivery system. Compare the results to those of a measurement standard, the DustTrak, which is also part of the DAFT hardware complement.



Astronauts Leroy Chiao and Jeff Williams have performed DAFT operations on ISS.

DAFT-3 P-Trak Vs. DustTrak



## Statistics on DAFT operations:

- DAFT-1 and -2 were delivered to the ISS in December, 2004 aboard Russian Progress Flight 16P and tests were conducted on February 22 and March 4, 2005. DAFT-3 and -4 were delivered to the ISS in July, 2006 aboard STS-121 and experiment operations were conducted on August 17th and 21st.

## Significant Results:

- During DAFT-1 and -2 operations, undisturbed air was sampled in the Destiny Module in front of EXPRESS Rack 4, in the module's aft end, and in the node. One test deliberately generated aerosol by repeatedly separating Velcro. The P-Trak appeared to operate nominally with no internal errors or nozzle clogging. Results indicate that the ISS atmosphere is substantially cleaner than the shuttle or a typical office environment.
- During DAFT-3 and -4 operations, three test points were successfully performed while sampling Arizona Road Dust. Results were compared with those from the DustTrak. The results indicate that the P-Trak functions nominally in a microgravity environment, satisfying the objective of the experiment.



# Investigating the Structures of Paramagnetic Aggregates (InSPACE-1) ISS On-Orbit Operations



PT: ISS Research Project  
PI: Prof. Eric Furst, UD  
PM: Donna Bohman, GRC  
PS: Juan Agui, GRC

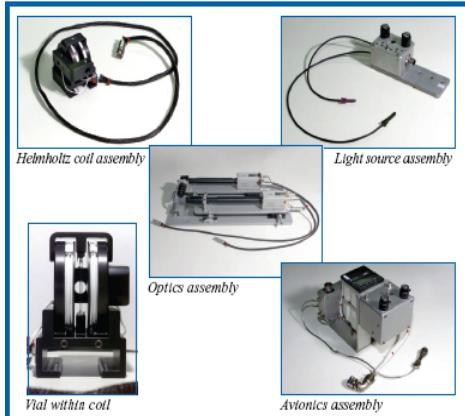
**Objective:** To (1) visually study the gelation transition in magneto-rheological fluids (MR) under steady and pulsed magnetic fields, and (2) determine the three-dimensional low-energy (equilibrium) structure of an MR emulsion in a pulsed magnetic field.

**Significance:** MR fluids are a class of smart materials capable of changing visco-elastic properties. Microgravity data will provide an assessment of the viscous-elastic properties for use in new brake systems, seat suspensions, robotics and vibration damping systems.

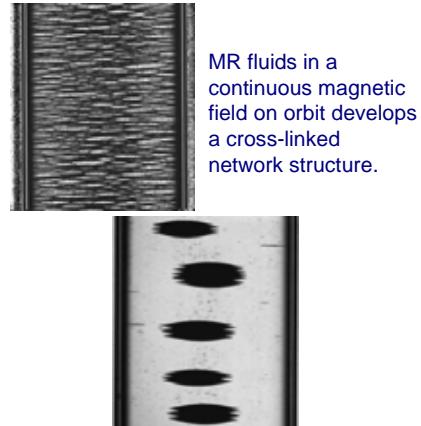
**Approach:** InSPACE consists of Helmholtz coil assemblies (electromagnets that produce a uniform magnetic field), each with a small borosilicate vial filled with MR fluid. Operated in the MSG, the crew installs a coil onto an optics assembly, adjusts electrical current and frequency causing the MR fluid to aggregate and form microstructures within the fluid.



Astronauts Don Pettit, William McArthur, and Jeffrey Williams have performed InSPACE operations on ISS.



InSPACE hardware components



MR fluids in a continuous magnetic field on orbit develops a cross-linked network structure.  
MR fluid in a pulsed field on orbit undergoes a novel structural alignment. This pulsed field mimics real applications where the field is repeatedly switched on and off.

## Statistics on InSPACE Operations

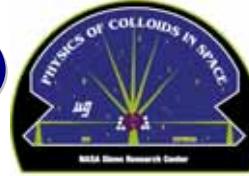
- InSPACE hardware and samples were launched to the ISS on 6/5/2002, and 11/23/2002 respectively.
- Primary operations occurred on ISS in Increment 7. The nominal revised test matrix was performed the week of 7/2/2003 with 26 runs / 41 test points completed.
- William McArthur successfully completed sample monitor runs to verify fluid dispersion in Increment 12 on 5/26/2006.
- Additional 5 science test runs were performed by Jeffrey Williams in Increment 13 the week of 6/5/06 including a Saturday Science run.
- Operations focused on a transition in structural configuration over a range of frequencies. Prevailing structures aligned in a columnar fashion along the magnetic field lines with elaborately shaped interfacial cross-sections.

## Significant Findings to Date

- New sheet-like structures with spiny interfaces in the cross-section were observed.



# Physics of Colloids in Space (PCS) ISS On-Orbit Operations

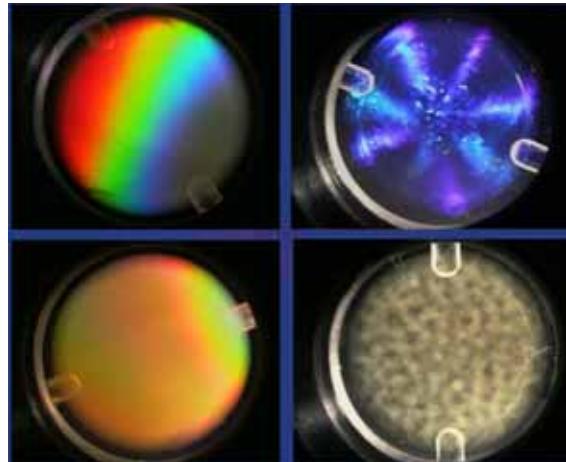


PT: ISS Research Project  
PI: Prof. David Weitz, Harvard  
Co-PI: Prof. Peter Pusey, U. Edinburgh  
PM: Michael P. Doherty, GRC  
PS: Dr. Subramanian Sankaran, NCSER

**Objective:** Use colloids in microgravity where they can serve as models for atoms; revealing material properties on a size range and time scale that we can measure.

**Significance:** Colloids are big enough and hence slow enough that they can be tracked using visible light. Yet, on earth, colloidal systems jam, sediment, and convect. In microgravity, PCS can study how nature forms order out of disorder. PCS has been used to study the physical properties and dynamics of four classes of colloidal systems: binary alloys, model critical fluids, growing fractals, and glasses that crystallize in microgravity.

**Approach:** Design and build a flight qualified light scattering instrument that can operate autonomously in an ISS Express Rack.

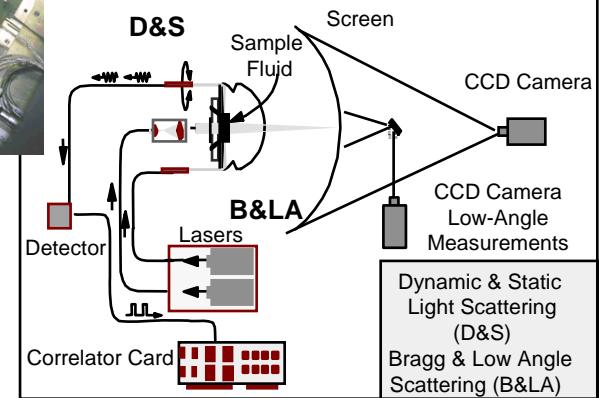


PCS On-Orbit Images



Carousel Cells

## PCS Diagnostic Diagram



## Statistics on PCS Operations

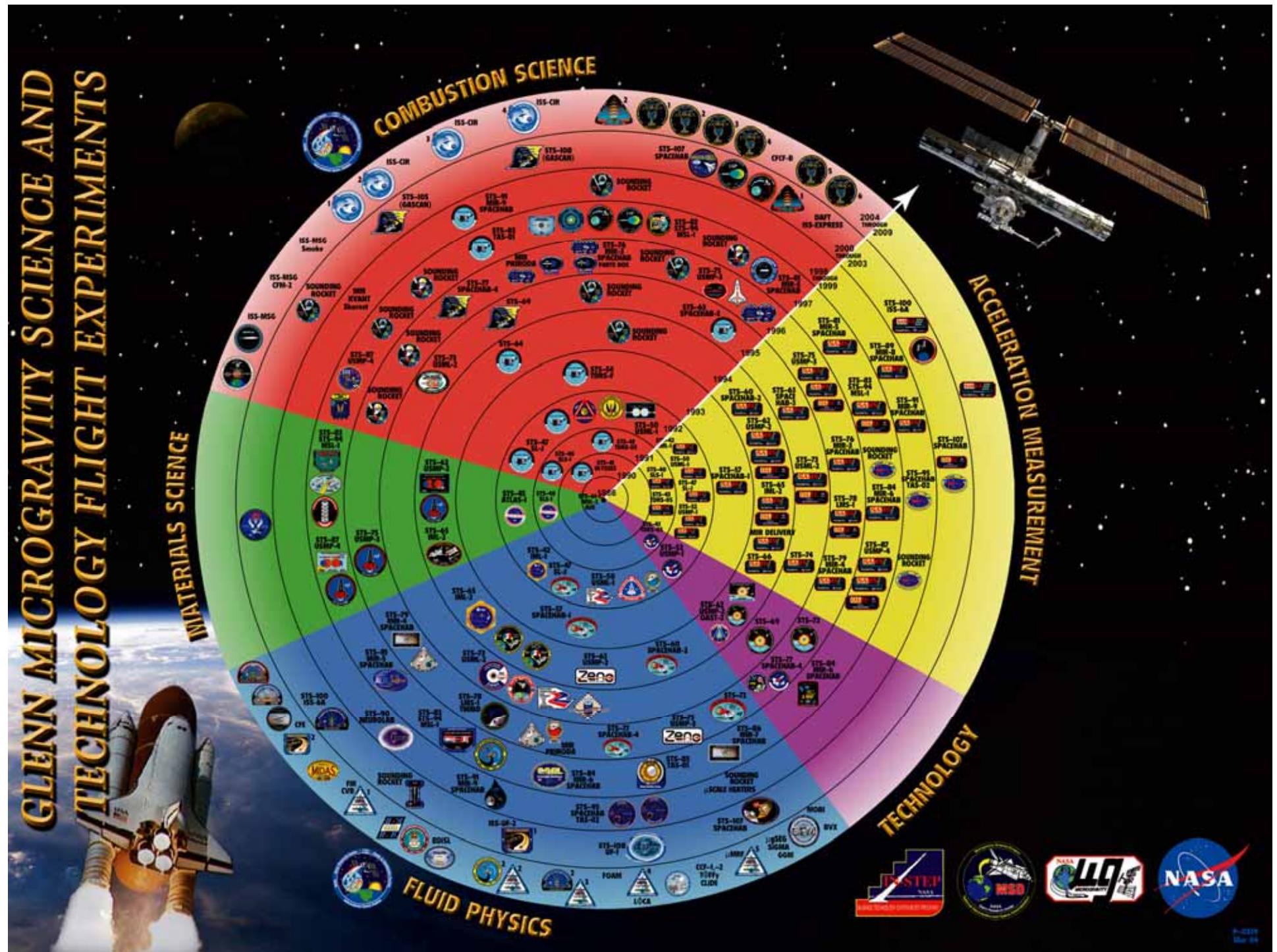
- Over 2,400 hours of on-orbit operations.
- Over 80% of the original science requirements were achieved.
- 24GB of data were acquired.

## Significant Findings

Unique findings observable only in microgravity:

- AB13 Sample: First measurements of crystallization kinetics of binary colloidal samples.
- Colloid-Polymer Critical Point Sample: Spontaneously de-mixed (phase separates) into colloid-rich and colloid-poor regions.
- Colloid-polymer Crystal: Showed a two-step growth process -- diffusion-limited clumping of the colloids, followed by growth of the crystals.
- Glass Samples: Crystallized in microgravity, only a glass on Earth.
- Numerous archival publications and presentations.

# GLENN MICROGRAVITY SCIENCE AND TECHNOLOGY FLIGHT EXPERIMENTS





An extensive experience base of low-gravity expertise exists at NASA which can support Exploration and Non-Exploration topics in both ground-based research and flight experiments venues"

The existing ISS facilities (CIR, FIR, MSG and MSRR) provide unique opportunities to examine low-gravity phenomena

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